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Description

Acoustic Determination of Moisture Content of a Gas Mixture

The present invention relates to a method of and a device for the acoustic determination of the moisture content of a multiple gas component gas mixture and in particular to a method and device employing acoustic velocity related measurements in the determination.

In medical applications involving the supply of a breathing gas to a patient pressurised air and oxygen are often mixed to attain an essentially binary component (oxygen/nitrogen) breathing gas mixture having a desired therapeutic oxygen content. This mixing is often carried out within a mechanical breathing aid, such as a ventilator, respirator or inhalation anaesthetic delivery system, which is designed to also control the subsequent delivery of the mixed breathing gas to a patient. The composition of the breathing gas requires close monitoring and it is well known to employ an acoustic, typically an ultrasonic, analyser connectable to or integral with the mechanical breathing aid for this purpose. Additionally, it may be desirable to also monitor the moisture content of the breathing gas so as to avoid dehydration of a patient receiving the gas which may occur if a dry breathing gas were provided.

The known acoustic analyser generally comprises an acoustic, typically ultrasonic, arrangement devised to emit acoustic energy into, detect acoustic energy from an acoustic path within the breathing gas and to generate from this an output signal containing acoustic velocity (V_S) related information; and a signal processor operable to receive the acoustic velocity related information and to determine therefrom the composition of the binary gas mixture according to the known equation:

$$V_s = \left(\frac{C_P^* R_M T}{C_V^* M^*} \right)^{1/2} \qquad (1)$$

where T is the absolute temperature (Kelvin) of the gas; R_M is the universal gas constant; and C_P^*, C_V^* and M^* are respectively the specific heat capacity at constant pressure, the specific heat capacity at constant volume and the molecular weight of the binary breathing gas mixture and are given by:

$$C_P^* = \frac{C_{P1} M_1 x_1 + C_{P2} M_2 x_2}{M_1 x_1 + M_2 x_2} \qquad (2)$$

$$C_V^* = \frac{C_{V1} M_1 x_1 + C_{V2} M_2 x_2}{M_1 x_1 + M_2 x_2} \qquad (3)$$

$$M^* = M_1 x_1 + M_2 x_2 \qquad (4)$$

where the subscripts 1 and 2 refer to a gas 1 and a gas 2 of the binary gas mixture and x_i is the fraction of the respective gas in the mixture so that

$$x_1 + x_2 = 1 \qquad (5)$$

The pressurised oxygen source connected to such a breathing aid typically originates from an external supplier and has negligible moisture content. However, the pressurised air is normally generated on-site and is made available at the breathing aid either from an attendant compressor or from a wall outlet connected to a central compressor located within the medical facility. A problem is that this pressurised air normally contains an unknown, small but significant amount of moisture. This moisture may be considered as a third gas, gas 3, component of the breathing gas mixture and can lead to errors in the determination of the composition of the breathing gas which is based on the equations (1)-(5) above.

Including this third gas in the equations (2)-(5) gives:

$$C_P^\bullet = \frac{C_{P1}M_1x_1 + C_{P2}M_2x_2 + C_{P3}M_3x_3}{M_1x_1 + M_2x_2 + M_3x_3} \qquad (2')$$

$$C_V^\bullet = \frac{C_{V1}M_1x_1 + C_{V2}M_2x_2 + C_{V3}M_3x_3}{M_1x_1 + M_2x_2 + M_3x_3} \qquad (3')$$

$$M^\bullet = M_1x_1 + M_2x_2 + M_3x_3 \qquad (4')$$

and

$$x_1 + x_2 + x_3 = 1 \qquad (5')$$

Since the fraction of moisture, x_3, in the mixture changes as the O_2 fraction changes and assuming all moisture in the mixture comes from the air (gas 1 say) then:

$$x_3 = k(1 - x_2) \qquad (6')$$

where k is the moisture fraction of the air before mixing

In order to reduce these errors it is known to determine the volume fraction (here x_3) of moisture (gas 3) within the breathing gas mixture other than by employing the acoustic analyser, such as by using a known moisture sensor, and then to insert the so measured value into the equations (2')-(6'). The composition of the "binary" gas breathing gas mixture can then be determined using the acoustic analyser.

However the addition of a dedicated moisture sensor adds expense and complexity to the analyser. To avoid these problems with the inclusion of a moisture sensor an estimation of a probable value for the volume fraction of moisture can be made without measurement and entered into the equations (2')-(6') as a constant for use within the acoustic analyser in the determination of the compositional information.

According to the present invention there is provided a method and a breathing aid operable according to the method as described in and characterised by the independent claims 1 and 5 respectively. By providing an analyser which during a calibration phase can operate to make an acoustic determination of the moisture content of the air being supplied to form the breathing gas mixture then the need a

separate moisture sensor is avoided whilst allowing an actual measure of the moisture content to be employed in subsequent compositional information determinations.

Usefully oxygen, being also supplied to form the breathing gas mixture, may also be provided separately during the calibration phase and the analyser configured to determine a calibration value from acoustic velocity measurements made therein to compensate within the analyser for errors not related to changes in a gas mixture.

Moreover, the analyser may be configured to generate a warning signal if the calculated value for the moisture content indicates an abnormally low or, particularly, an abnormally high moisture level in the air being supplied to the mechanical breathing aid.

These and other advantages will become apparent from a consideration of the following description of an exemplary embodiment of the present invention made with reference to the accompanying figures, of which:

Fig. 1 shows a schematic of a mechanical breathing aid according to the present invention; and
Fig. 2 shows a flow diagram of a method of operation of an acoustic analyser according to the invention utilised in the breathing aid of Fig. 1.

Considering now Fig. 1, a mechanical breathing aid 2 is shown and is described below only in the detail necessary for an understanding of the invention. It will be appreciated that functions and components not described below but which are typically found in mechanical breathing aids may be included within the breathing aid 2 but are not essential to the invention.

The mechanical breathing aid 2 comprises a first inlet 4, connectable to a source of one or other of pressurised air and pressurised oxygen (not shown), and a second inlet 6 connectable to the other of the pressurised air or oxygen sources (not shown). A mixing chamber 10 is provided in gas communication with each of the first 4 and the second 6 inlets via a controllable flow regulator 12, such as may be formed using a flow control valve 12a,12b respectively coupled to an associated one of the inlets 4,6, which is adjustable to vary the relative amounts of the gases from the inlets 4,6 entering the mixing chamber 10. A microprocessor based control unit 14 is arranged in operable connection with the flow regulator 12 and is configured to generate a control signal for use by the flow regulator 12 to establish a desired binary breathing gas mixture within the mixing chamber 10. In the present embodiment the controller 14 is also arranged in operable connection with a flow direction controller 52 which is movable in response to a control signal therefrom between a first position in which gas from the mixing chamber 10 is able to flow to a supply outlet 50 and a second position in which gas from the chamber 10 enters an exhaust line 54 to be removed from the breathing aid 2 via an exhaust outlet 56.

An acoustic analyser 16 is operable to generate acoustic velocity related information for acoustic energy after interaction with the binary gas, for example at a location downstream of the mixing chamber 10, and to determine therefrom an oxygen content value for the binary gas for use by the control unit 14 in the generation of the control signal. A temperature sensor 58, here located in thermal contact with gas in the mixing chamber 10, is provided to generate a signal indicative of the gas temperature (T) at the acoustic analyser 16.

The acoustic analyser 16 comprises an ultrasonic arrangement 18 and a signal processor 20 which has an internal random

access memory (RAM) 22. The ultrasonic arrangement 18 of the present embodiment comprises a pair of ultrasonic transducers 24a,24b, and a transducer controller/timer 28 in operable connection with the transducers 24a,b. The transducers 24a,b are here disposed opposing one another to delimit an ultrasound path which traverses a gas conduit 26 connected to internal the mixing chamber 10, for example, at an angle to the gas flow direction within the conduit 26. This configuration of transducers 24a,b which is used in the present embodiment is well known and is preferentially employed to facilitate an additional gas flow measurement with the ultrasonic arrangement 18.

The controller/timer 28 is designed to operate a one of the pair (24a say) to emit an ultrasound pulse along the ultrasound path and to operate the other one of the pair (24b say) to generate a signal indicative of the arrival of the so emitted pulse after its interaction with gas within the conduit 26. A microprocessor (not shown) within the controller/timer 28 is programmed to determine from the generated signal a transit time (t) for the ultrasound along the length (L) of the ultrasound path and from this a velocity value (V_S) for ultrasound in the gaseous medium within the conduit 26 using an algorithm based on the equation:

$$V_S = L/t \qquad (7)$$

The signal processor 20 is arranged to receive this velocity value (V_S) and is programmed to determine compositional information for the gaseous medium using algorithms based on the equations (1) and (2-5) or (2'-6'), as appropriate and, in the present embodiment, the value of the temperature (T) from the sensor 58 .

Considering now the operational flow diagram that is illustrated in Fig. 2 for the acoustic analyser 16. In the

present embodiment a determination is made at step 30 as to whether or not the mechanical breathing aid 2 is in a calibration procedure (YES) or a measurement procedure (NO). This can be done, for example, by adapting the control unit 14 to check for a user input signifying a start of a calibration procedure and then to output a signal to the signal processor 20 indicative of this. Alternatively, for example, a calibration procedure may be entered automatically at the start up of the breathing aid 2 and/or at predetermined time intervals during its use or some combination of the two may be used.

Irrespective of how the determination is made at step 30, on entering a calibration procedure the control unit 14 is configured to control the flow regulator 12 to allow passage of only air from the associated inlet 4 or 6, through the mixing chamber 10 and to the acoustic analyser 16 where, at step 32, a velocity value for ultrasound in the air is generated within the controller/timer 28 from which, at step 34 the signal processor 20 is programmed to calculate an oxygen concentration value based on the equations (1) and (2'-5'), assuming air to be a gas mixture of nitrogen, oxygen. In the present embodiment, at step 36, the signal processor 20 is further programmed to calculate a value for the moisture content of the air from a deviation between the previously calculated oxygen content and an expected oxygen content (20.9 % for dry air the value of which may be stored in the RAM 22) and to store this value for the moisture content in the RAM 22. This may be done iteratively by adjusting the value of (k) in equation (6') until the calculated value of oxygen concentration equals the expected value of here 20.9%.

Additionally, the signal processor 20 may be programmed to compare the so calculated moisture content value with one or both upper and lower limit values and to generate a warning

signal if the so calculated value lies outside one or other limit.

In an optional refinement to this procedure, illustrated by the broken line path in Fig. 2, a calibration value may be calculated preferably, but not essentially, before the determination of the velocity value for ultrasound in air at step 32. In this procedure the control unit is configured to further control the flow regulator 12 to allow passage of only the dry oxygen from the other inlet 4 or 6, through the mixing chamber 10 and to the acoustic analyser 16. The acoustic analyser 16 operates to determine a value for the oxygen concentration (step 40) from equation (1) using ultrasonic velocity measurements in the oxygen (step 38) and to then calculate a calibration value based on a deviation of the determined oxygen concentration from the expected concentration (100 % for dry oxygen). This calibration value may then be used within the signal processor 20 to compensate subsequent compositional information calculations, made during the calibration or measurement procedures, for errors which are unrelated to gas compositional changes, such as errors in the value of the length (L) of the ultrasound path between the transducer pair 24a,b.

After a calibration procedure, as described above, has been undertaken the moisture content value for the air being used within the mechanical breathing aid 2 is available for use during compositional information calculations which will be made during subsequent measurement procedures. Thus, if at step 30 it is determined that a measurement procedure is required (NO), that is the controller 14 of the mechanical breathing aid 2 is operating to generate an oxygen/air breathing gas mixture within the mixing chamber 10, then the acoustic analyser 16 of the present embodiment is configured to operate according to the process steps 44,46 and 48 which are illustrated in the Fig. 2. During the measurement procedure the ultrasonic arrangement 18 is operated to obtain

ultrasonic velocity information for the gas mixture and to provide this to the signal processor 20 which is programmed to access and retrieve the moisture content value that is stored in the RAM 22 (step 44). The signal processor 20 is programmed to then calculate an oxygen content value for the gas mixture based on an algorithm using the equations (1) and (2′-6′) as necessary and the velocity and moisture content values (step 46). The signal processor 20 is configured to then generate a control signal which contains the so calculated oxygen content value (step 48) for use by the controller 14 in establishing a desired gas mixture for supply from the breathing aid 2 through an outlet 50.

It will be appreciated that the inclusion of a dedicated signal processor 20 enhances the flexibility of the analyser 16, making it a stand-alone component that can be used in a variety of situations but that, without departing from the invention as claimed, some or all of its functionality may be included in a suitably programmed controller 14 to make the analyser a machine-specific component at a reduced element cost.

Claims

1. A method of determining in an acoustic analyser a moisture content of air comprising the steps of:

a) introducing into the acoustic analyser during a calibration procedure (30) an air sample;

b) operating (32) the acoustic analyser to generate acoustic velocity related information for the air sample; and

c) determining (34) within the analyser compositional information for one or both of oxygen content and nitrogen content of the air sample using the generated acoustic velocity related information;

characterised by the steps of:

d) determining (36) within the analyser a deviation of the determined compositional information from an expected compositional information for dry air; and

e) calculating (36) within the analyser a moisture content value for the air sample from the determined deviation of compositional information.

2. A method as claimed in claim 1 characterised by the additional steps of:

a) introducing into the acoustic analyser a dry gas sample having a known composition of one or more constituent gases;

b) operating (38) the acoustic analyser to generate acoustic velocity related information for the dry gas sample;

c) determining (40) within the analyser compositional information for a one of the constituent gases of the dry gas sample using the generated acoustic velocity related information; and

d) calculating (42) within the analyser a calibration value dependent on a deviation of the determined compositional information from the known composition for use in providing a corrected compositional information.

3. A method as claimed in claim 2 characterised in that the step a) of introducing into the acoustic analyser a dry gas sample consists of introducing oxygen as the sample.

4. A method as claimed in any preceding claim characterised by the additional steps of:

a) introducing into the analyser during a measurement procedure an oxygen/air gas sample;

b) operating (44) the acoustic analyser to generate acoustic velocity related information for the binary gas sample; and

c) determining (46) within the analyser compositional information for the oxygen content the binary sample using the generated acoustic velocity related information and the calculated moisture content value for the air from the calibration procedure.

5. A mechanical breathing aid (2) comprising a first inlet (4) connectable to a source of air; a second inlet (6) connectable to a source of oxygen; a mixing location (10) in gas communication with the first and the second inlets (4;6) at which controlled amounts of air and oxygen from the respective inlets (4;6) are mixed to form a breathing gas; and an acoustic analyser (16) configured to operate during a measurement procedure to access a moisture content value for air from the source of air, to generate acoustic velocity related information for acoustic energy after interaction with the breathing gas and to determine therefrom an oxygen content value characterised in that the acoustic analyser (16) is further configured to generate during a calibration procedure acoustic velocity related information for acoustic energy after interaction with air from the source of air; to determine therefrom an oxygen content value for the air and to calculate therefrom the moisture content value for air.

Abstract

Acoustic Determination of Moisture Content of a Gas Mixture

A mechanical breathing aid (2) comprises first and second inlets (4;6) connectable in mutual exclusion to a source of air and a source of oxygen. A mixing location (10) is provided in gas communication with the first and the second inlets (4;6) at which controlled amounts of air and oxygen from the respective inlets (4;6) are mixed. An acoustic analyser (16) is configured to operate during a measurement procedure to access a moisture content value for air from the source of air, to generate acoustic velocity related information for acoustic energy after interaction with the breathing gas and to determine therefrom an oxygen content and to operate during a calibration procedure to generate acoustic velocity related information for acoustic energy after interaction with air from the source of air and to determine therefrom an oxygen content value for the air from which is determined a moisture content value for air.

FIG. 1

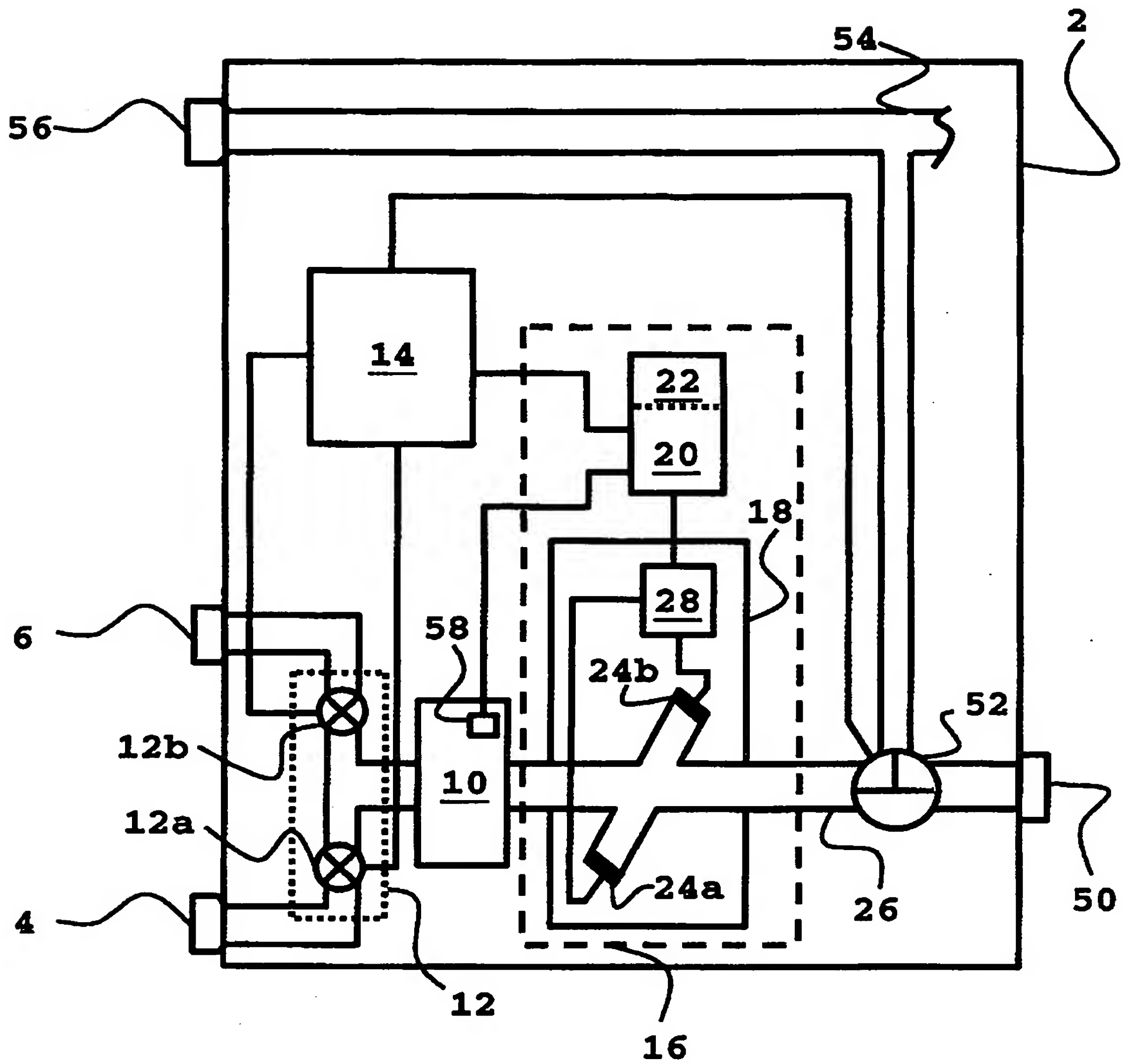

Fig. 1

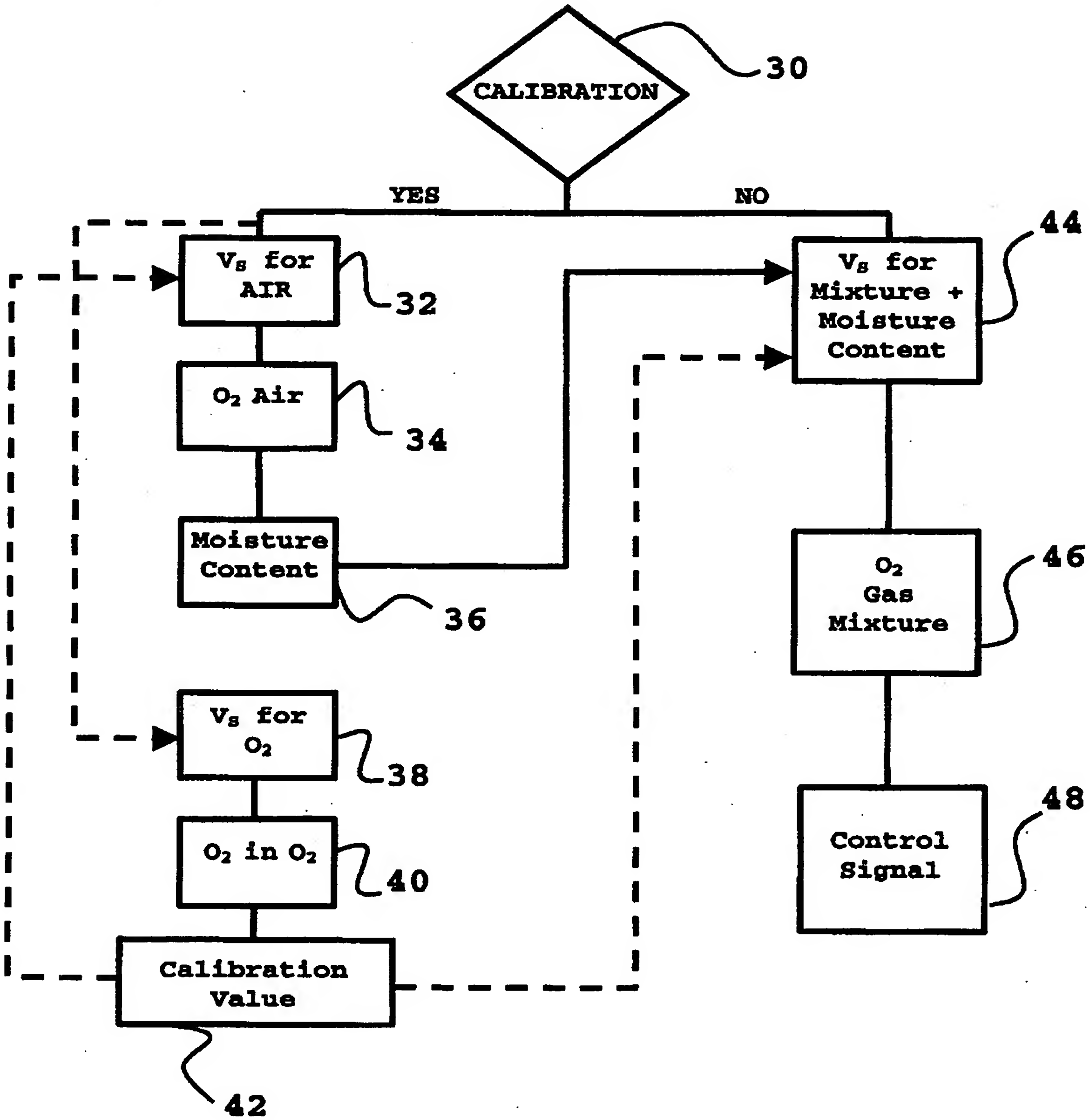
CALIBRATION
30
YES
NO
Vs for AIR
32
O2 Air
34
Moisture Content
36
Vs for O2
38
O2 in O2
40
Calibration Value
42
Vs for Mixture + Moisture Content
44
O2 Gas Mixture
46
Control Signal
48

Fig. 2